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An analysis of biodiesel fuel from waste edible oil in Taiwan

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Abstract

Taiwan is a high energy-importing nation with more than 98% of our energy supplied by imported fuels in 2004. The diversification of kinds and sources of primary fuel is becoming vital energy issues in the country. In this regard, biomass energy like biodiesel fuel from waste edible oil is thus becoming attractive due to the environmental and energy policies for promoting sustainable development and environmental pollution mitigation in Taiwan. The objective of this paper is to present an analysis of energy utilization from waste edible oil for the diesel production in Taiwan. The description in the paper is thus summarized on current status of diesel fuel and edible oil supply and consumption, and waste edible oils, and then centered on new/revised promotion legislation/regulations especially concerning the waste-to-biodiesel in the measures of environmental protection and economic/financial incentives. Finally, we survey the first demonstration plant in the production of biodiesel from waste edible oil including process description and benefit analysis, which has started to be operated in October 2004 on an industrial scale of 3000 metric tons per year.

Keywords: Biodiesel fuel; Waste edible oil; Energy utilization; Promotion measure; Energy policy

Contents

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1. Introduction

Taiwan, located in the southeastern rim of Asia, is a densely populated island country (i.e. population density: 640 people/km^2; total area: 36,000 km^2) with only limited natural resources. In 2003, the imported energy accounts up to 98% of the total energy supply in this subtropical country. The energy supply totaled 121.22 million kiloliters of oil equivalent (KLOE) in 2003, in contrast to 58.57 KLOE in 1990 [1]. In recent years, the environmental issues such as global warming and acid rain are consecutively arousing public concerns. In response to the Kyoto Protocol adopted in December 1997, Taiwan convened the National Energy Conference in May 1998. One of the most important conclusions is to increase the share of renewable energy in Taiwan's total energy supply, up to 3% in 2020. For this reason, energy strategies and policies for promoting renewable energy must be active to provide some environmental and financial/economic incentives [2].

The energy utilization from biomass resources has received much attention since the mid-1990s. The energy in biomass (called biomass energy) from plants, animals (that eat plants or other animals) or wastes that they produce originally comes from solar energy through the photosynthesis process. The energy supply from domestic waste materials is especially noted in that it not only enhances fuel diversification, but also eliminates the environmental pollution. Of the many energy productions from food wastes or food processing wastes, especially in waste edible oils, seem to be attractive based on bioresource sustainability, environmental protection and economic consideration. The energy obtained from waste edible oils is a form of renewable energy and, in principle,

utilizing this energy does not add carbon dioxide, which is one of the major greenhouse gases, to the atmospheric environment, in contrast to fossil fuels [3]. Due to the extremely low contents of sulfur and nitrogen in the food waste, its direct utilization as fuel in the combustion utilities (e.g. internal combustion engine) generally generates less environmental pollution and health risk as compared to traditional fossil fuels.

It is well-known that the hydrocarbons in the diesel fuels include a diversity of paraffins, olefins, naphthenes and aromatics [4,5]. Therefore, carbon numbers of these hydrocarbons present in the diesel fuels are mostly in the ranges of 12–22. Due to its high energy conversion and power output in diesel engines, diesel fuel have been extensively used in heavy truck, city transport bus, electric generator, farm equipment, etc. On the other hand, edible oils including vegetable oils and animal fats are principally glycerides (i.e. triglycerides) formed from the glycerol and higher fatty acids (C_{12}–C_{22}) such as lauric, myristic, palmitic, stearic, oleic, linolenic, and linoleic acids [4,6,7]. By way of transesterification, the reaction of triglycerides with alcohol (e.g. methanol) under the caustic catalyst (e.g. potassium hydroxide) is processed to produce glycerol and monoalkyl esters [4,8–14], which are known as biodiesel and can be potentially used as alternative diesel fuels in compression-ignition (diesel) engines [15–18]. Biodiesel, one of green fuels and/or clean energies, is compatible with traditional petroleum-based diesel and both can be completely blended without any stratification. From the viewpoint of its chemical composition and properties, biodiesel fuels are biogedradable, low toxic, and emit less air pollutants than hydrocarbon-based diesel. However, the use of biodiesel shall face to its high cost relative to petroleum-based oils, and some problems related to the decrease power output and torque force and to the increase in NO_x emissions with increasing biodiesel content in the blends [15].

The catalytic conversion of waste edible oil by the transesterification process into biodiesel fuel has the advantage of both economic and environmental benefits. In this regard, the biodiesel fuel has been demonstrated to be successfully produced from waste edible oils by an alkali-catalyzed transesterification process [19–28], and can be considered as alternative fuels in diesel engines and other utilities [29–35]. Under the policy encouragement and economic/financial incentives by the central agencies (i.e. Environmental Protection Administration and Bureau of Energy), the first demonstration plant in the production of biodiesel fuels from waste edible oils on an industrial scale of 3000 m^3 per year has started to be commercially operated in October 2004 [36].

Because of the increasing trend in crude oil prices, limited resources in fossil fuels and environmental concern in ambient air quality, the objectives of this paper will give a comprehensive review on the potential feasibility and regulatory incentives for promoting biodiesel production and from waste edible oils in Taiwan. The main subjects covered in this paper are described in the following key elements:

- Current status of total energy supply, and diesel fuel supply and consumption
- Status of oilseeds and edible oils supply and consumption
- Generation and recycling of waste edible oils
- Environmental regulations and policies for encouraging biodiesel fuel
- Economic policies for financing biodiesel fuel
- Energy policies for promoting biodiesel fuel
- Demonstration case: biodiesel production from waste edible oils.

2. Current status of total energy supply, and diesel fuel supply and consumption

2.1. Current status of total energy supply

Although Taiwan is a country rich in renewable energy resources such as solar energy and wind energy [2], it is well-known that the nation is a densely populated island with nearly no fossil energy resources such as crude oil and natural gas. It, undoubtedly, is a high energy-importing country. As seen in Table 1, national reliance on imported energy significantly rose from 87.6% in 1983, 92.4% in 1988, 95.9% in 1993, 96.1% in 1998, to 97.9% in 2003. It has also been observed that the imported reliance on petroleum oil gradually decreased from 69.9% in 1983, 57.4% in 1988, 55.3% in 1993, 53.4% in 1998, to 51.8% in 2003 due to the nation's energy policy on efforts to diversify imported energy sources. With respect to the total energy supply in the past two decades (1983–2003) in Taiwan (see Table 1) [1], some notable points are further addressed as follows:

Prior to 1983, the percentage of energy supply from indigenous production is above 13% mainly due to coal exploitation domestically. The portion, which the domestic production accounted for, has gradually diminished since then. In 2003, 98% of total energy supply must be dependent on oversea import.

The energy supply increased from 35.45 million KLOE in 1983 to 121.22 million KLOE in 2003. The growth rate of energy supply averaged out to about 6.3%. In contrast, the growth rate is consistently parallel to the average economic growth (i.e. 6.0%) during 1987–2004 [37].

In response to the oil crisis, the government has diversified its energy sources. Approximately 50% of the total energy supply in 2003 came from petroleum, compared to 70% in 1983. The second largest imported energy source was coal with a 33% share of the energy supply. Other energy supply sources also include nuclear power (8%), natural gas/liquefied natural gas (7%), hydroelectric power (1%), and renewable energy (below 1%) [38].

Table 1
Total energy supply during 1983–2003 in Taiwan

Item	1983	1988	1993	1998	2003
Total supply (million kiloliter oil equivalence)	35.45	51.40	68.39	92.46	121.22
Indigenous energy	4.38	3.91	2.78	3.61	2.58
Petroleum	0.13	0.14	0.06	0.05	0.05
Coal	1.54	0.84	0.23	0.05	–
Natural gas	1.47	1.40	0.82	0.87	0.12
Hydroelectric power	1.24	1.53	1.67	2.64	1.71
Renewable energy	–	–	–	–	0.70[a]
Imported energy	31.07	47.49	65.61	88.85	118.64
Petroleum	21.71	27.25	36.26	47.43	61.48
Coal	4.66	12.63	18.26	26.25	39.47
Nuclear power	4.70	7.61	8.53	9.15	9.66
Liquefied natural gas (LNG)	–	–	2.56	5.62	8.03

Ref. [1].
[a]The indigenous energy source is mostly from biogases in the sanitary landfills and some anaerobic wastewater treatment plants [38].

By the year of 2020, considerable portions (about 14 and 4%, respectively) of the energy supply will be projected from natural gas/liquefied natural gas and renewable energy (especially in wind energy and solar energy), respectively [39]. This gradual increase in clean and green energy supply is mainly reflected on the Taiwan's response to the economic, energy and environmental (3E) policies on sustainable development in the near future.

2.2. Current status of diesel fuel supply and consumption

According to the data by the Bureau of Energy under the Ministry of Economics Affairs [1], diesel fuel supply and consumption in Taiwan is listed in Table 2. Some important features in Table 2 are featured as follows:

In Taiwan, about 5.82 million KLOE (i.e. 4.95 million metric tons) of diesel oil was consumed in 2003, an increase of 15.1% since 1993 and 104.4% since 1983, or an annual average growth rate of 3.6% during 1983–2003. On the other hand, about 11.49 million KLOE (i.e. 9.77 million metric tons) of diesel oil was supplied in 2003, an increase of 115.6% since 1993 and 236.0% since 1983, or an annual average growth rate of 6.1% during 1983–2003.

Table 2
Amounts of diesel oil supply and consumption during 1983–2003 in Taiwan

Year	Supply[a]		Consumption	
	Total (10^3 KLOE)[b]	Percentage (%)[c]	Total (10^3 KLOE)	Percentage (%)[d]
1983	3419.0	15.43	2849.0	15.07
1984	3638.8	15.32	2931.5	15.63
1985	3306.6	13.87	2983.7	16.02
1986	3028.1	11.68	3206.5	15.49
1987	3976.5	14.67	3509.9	16.22
1988	3596.4	11.55	3764.3	15.03
1989	4446.9	13.52	4142.0	15.01
1990	4862.9	14.50	4373.1	15.28
1991	5118.7	15.35	4600.4	15.52
1992	4872.2	14.36	4692.6	15.68
1993	5326.8	14.67	5059.5	15.79
1994	5569.4	13.59	5534.7	16.05
1995	6188.7	13.97	5554.0	15.10
1996	6461.1	14.53	5383.3	14.55
1997	6688.9	14.35	4950.9	13.05
1998	7079.3	14.91	5226.5	13.47
1999	7798.4	13.64	5767.0	14.08
2000	7784.4	12.61	5949.3	14.47
2001	8721.1	13.26	5665.9	13.27
2002	9688.5	14.40	5988.3	13.54
2003	11,487.0	15.26	5822.1	12.91

Source: [1].
[a]Diesel oil supply is mostly from indigenous production in the refineries.
[b]KLOE, kiloliter oil equivalent.
[c]The percentage is based on the total petroleum product supply.
[d]The percentage is based on the total petroleum product consumption.

Overall, the ratio of diesel oil to all petroleum products (including liquefied petroleum gas, motor gasoline, jet fuel, kerosene, diesel oil, fuel oil, lubricant, naphtha, etc.) approximated to 14%.

Since 1997, the amount of diesel oil supply was obviously larger than that of diesel oil consumption, showing that most of the remaining portions were exported to China and Southeast Asian nations.

Recently, it has been demonstrated that the oil saving and greenhouse gases (e.g. carbon dioxide) emission reduction in diesel motor is superior to those in gasoline motor. From the point of view of concerning global warming and lasting high oil price, the diesel oil consumption will be expected to increase in the near future.

3. Status of oilseeds and edible oils supply

3.1. Status of oilseeds supply

According to the data by the Council of Agriculture in Taiwan [40], the oilseeds supply in Taiwan is listed in Table 3. Some important features in Table 3 are described as follows:

About 2.5 million metric tons of oilseeds were supplied in the past decade, showing that the oilseeds supply maintains a stable trend. Further, the trend is closely in connection with the data on population growth (e.g. $21{,}126 \times 10^3$ persons in 1994 vs. $22{,}535 \times 10^3$ persons in 2003), population structure (e.g. percentage of population over 65 years of age, 7.4 in 1994 vs. 9.2% in 2003) and gross national product (i.e. US$ 11,806 in 1994 vs. 13,157 in 2003) during the period [41].

In Taiwan, most cultivation soils were used to plant paddy rice, corn and a diversity of vegetables. Therefore, import dependence of oilseeds except peanut is over 99%. For example, import and domestic production amounts of soybean contributed 2455×10^3 and 0.3×10^3 metric tons in 2003, respectively.

Table 3
Supply amounts of pulses and oilseeds during the years of 1994–2003 in Taiwan

Year	Soybean				Peanut			Sesame			Others			Total supply[a]
	P	*I*	*E*	*S*	*P*	*I*	*E*	*P*	*I*	*E*	*P*	*I*	*E*	
1994	12.0	2392.6	0.6	−45.8	80.6	4.5	0.2	0.3	35.7	–	11.7	111.9	6.9	2687.3
1995	8.9	2585.7	1.9	−82.5	92.2	6.1	0.2	0.3	34.2	–	11.0	99.7	3.9	2914.5
1996	9.7	2690.5	3.0	20.6	79.9	4.4	0.2	0.3	31.7	0.0	13.2	112.3	3.1	2915.0
1997	4.7	2758.1	2.0	125.7	84.2	4.5	0.2	0.4	33.4	0.0	12.2	121.4	3.2	2887.8
1998	1.5	2002.6	22.8	−170.9	68.3	4.0	0.3	0.4	30.0	0.0	10.2	111.0	2.6	2373.2
1999	0.4	2357.7	3.3	235.1	67.2	4.5	0.3	0.5	33.2	0.0	9.1	118.4	2.4	2349.7
2000	0.3	2302.6	2.9	109.2	79.1	4.9	0.2	0.6	34.7	0.0	8.0	118.7	2.3	2434.4
2001	0.3	2443.3	6.3	289.7	56.1	4.5	0.2	0.6	32.5	0.0	5.2	109.1	2.4	2353.0
2002	0.4	2535.2	7.7	232.7	77.5	8.1	0.3	0.5	37.4	0.0	8.0	135.4	3.6	2558.0
2003	0.3	2455.1	12.4	60.3	73.5	7.0	0.3	0.6	32.7	0.0	8.2	133.1	2.7	2634.7

Source: [40]; unit: thousand metric tons.
[a]Supply = production (*P*) + import (*I*) − export (*E*) − change in stock (*S*).

Among oilseeds, the ratio of soybean supply to total supply is close to 90%. For example, the ratios of bean supply to total oilseed supply in 1994 and 2003 were 91.2% (i.e. 2449.8×10^3 metric tons vs. 2687.3×10^3 metric tons) and 90.4% (i.e. 2382.7×10^3 metric tons vs. 2634.7×10^3 metric tons), respectively.

3.2. Status of edible oils supply and consumption

Due to the high contents of carbohydrates, proteins and lipids (fats or oils) in oilseeds, one of the main applications is to be processed to edible oils (vegetable) for human consumption (diet). Table 4 shows the data on edible oils supply during the years of 1994–2003 in Taiwan [40]. As expected, soybean oil is the most important edible oils in Taiwan. Its production, consumption and inventory have been surveyed by Taiwan Vegetable Oil Manufacturers' Association as listed in Table 5 [42]. Further, the

Table 4
Supply amounts of edible oils during the years of 1994–2003 in Taiwan

Year	Soybean oil				Vegetable oils				Lard oil			Animal oils			Total supply[a]
	P	*I*	*E*	*S*	*P*	*I*	*E*	*S*	*P*	*I*	*E*	*P*	*I*	*E*	
1994	331.8	0.7	3.9	−9.7	355.8	126.3	6.3	−9.7	61.4	18.9	1.9	61.4	136.1	4.2	678.9
1995	363.0	16.5	4.8	30.4	388.0	135.7	8.2	30.4	62.9	17.3	2.8	62.9	135.3	4.6	678.5
1996	363.3	2.9	29.1	−25.4	385.7	127.3	33.6	−25.4	64.7	3.2	3.2	64.7	128.3	6.3	691.7
1997	358.1	42.9	2.7	23.0	381.8	186.5	6.3	23.0	51.3	4.8	2.1	51.3	118.6	4.5	704.5
1998	295.6	26.5	0.9	−22.9	316.1	150.0	4.4	−22.9	40.1	5.5	0.1	40.1	105.1	3.2	626.7
1999	288.7	75.3	1.3	7.3	310.3	237.6	5.1	7.3	37.0	8.3	4.1	37.0	148.2	6.7	714.0
2000	298.3	20.9	1.3	−5.7	321.8	202.1	5.4	−5.7	41.4	2.9	1.7	41.4	120.5	4.5	681.6
2001	292.9	18.5	1.2	−8.2	312.8	187.2	5.2	−8.2	43.3	0.4	2.9	43.3	109.8	6.4	649.7
2002	313.1	37.3	0.8	−0.6	337.7	200.3	7.9	−0.6	42.1	15.1	5.0	42.1	119.1	9.8	682.1
2003	325.7	42.5	1.3	5.9	348.1	213.2	8.8	5.9	40.2	16.9	6.4	40.2	121.2	12.3	695.7

Source: [40]; unit: thousand metric tons.
[a]Supply = production (P) + import (I) − export (E) − change in stock (S).

Table 5
Amounts of production and consumption on soybean oil during 1995–2003 in Taiwan

Year	Production	Consumption	Inventory
1995	407,069	387,976	28,710
1996	409,519	416,970	21,259
1997	411,935	417,805	15,389
1998	385,270	387,422	13,237
1999	447,362	425,835	34,764
2000	398,132	407,644	25,253
2001	396,939	400,938	21,254
2002	388,035	361,488	20,730
2003	365,097	392,169	17,121

Source: [42]; unit, metric ton.

Table 6
Supply amounts of edible oils during the year of 2000 in Taiwan

Edible oil	*P*	*I*	*E*	Total supply[a]	Percentage (%)
Vegetable oil					
Soybean	398.1	20.9	1.3	417.7	55.3
Palm	0.0	71.1	0.1	71.0	9.4
Sunflower seed	0.0	30.9	0.0	30.9	4.1
Sesame	10.9	0.6	3.0	8.5	1.1
Peanut	7.4	0.0	0.0	7.4	1.0
Corn	3.0	3.8	0.0	6.8	0.9
Coconut	0.0	6.6	0.0	6.6	0.9
Safflower	0.0	0.1	0.0	0.1	0.0
Rapeseed (canola)	0.0	44.9	0.0	44.9	5.9
Olive	0.0	6.6	0.0	6.6	0.9
Animal oil					
Lard oil	49.2	14.4	2.8	60.8	8.1
Beef oil	0.0	88.9	0.0	88.9	11.8
Other edible oils	0.0	4.6	0.2	4.4	0.6
Total	468.6	293.4	7.4	754.6	100.0

Source: [43]; unit: thousand metric tons.
[a]Supply = production (P) + import (I) − export (E).

contribution of edible oils in 2000 is also summarized in detail in Table 6 [43]. According to the data in Tables 4–6, some important points are featured as follows:

About 700,000 metric tons of edible oils supply were supplied in the past decade, showing that the diet supply maintains a stable trend, which is closely parallel to the data on oilseeds supply as described above. On the other hand, the daily intake level of edible oils per person (about 70 g) was also kept constant during the period, which was consistent with the survey data on 80 g for male and 61 g for female [44].

Due to the prevail in vegetable diet, the ratio of vegetable oils to edible oils had a increasing trend. For example, the ratios of vegetable oils supply to total edible oils supply in 1994 and 2003 were 71.5% (i.e. 485.6×10^3 metric tons vs. 678.9×10^3 metric tons) and 79.6% (i.e. 546.6×10^3 metric tons vs. 695.7×10^3 metric tons), respectively.

The most common edible oil was still soybean oil. However, the ratio of soybean supply to total vegetable oil supply had decreased in the past decade. For example, the ratios in 1994 and 2003 were 71.7% (i.e. 338.3×10^3 metric tons vs. 485.6×10^3 metric tons) and 66.0% (i.e. 361.0×10^3 metric tons vs. 546.6×10^3 metric tons), respectively.

A diversity of imported vegetable oils such as sunflower oil and rapeseed (canola) have become prevailing for the purpose of diet control and body health in Taiwan, resulting in the dependence of soybean oil in incline.

4. Generation and recycling of waste edible oil

In Taiwan, it was reported that the local consumption of edible oils amounted to about 700,000 metric tons per year [40]. According to the data on approximately 200,000 metric

tons of waste vegetable oils discarded annually [9], and about 2 million metric tons of edible oil consumption in Japan [45], approximately 70,000 metric tons of waste edible oil was thus generated annually in Taiwan. The generation amount estimated by the authors is smaller than that (about 140,000 metric tons) by other researchers mainly due to the different generation factor adopted [46]. However, waste edible oil was mainly generated from commercial services and food processing plants as depicted in Fig. 1 [47]. The former, called as waste (used) cooking or frying oils, are generally from restaurants, fast food chains and households as a result of several deteriorative changes of composition, color and stability [9]. For example, the hydrolysis of triglycerides is often occurred in deep frying or cooking, resulting in the excess release of free fatty acids in edible oil. The later is industrially derived from the processing of edible oils, which includes degumming, neutralization, bleaching and deodorization. Among these processes, there has been much attention over the past few years with regard to disposal problems associated with spent bleaching earth because such clay waste still contains 20–35% edible oil by weight [48–50]. Historically, there is no efficient way to dispose of this waste material, which was simply dumped into sewers and/or landfills without any treatment causing several environmental problems such as odor and self-ignition. Recently, resource recycling of waste edible oils and spent bleaching earth has been considered as one of commercial/industrial waste reuse types under the authorization of Waste Disposal Act [51,52]. Also, several local governments in Taiwan have started to implement the mandatory garbage sorting (i.e. recyclable waste, kitchen waste and general waste) and collect the waste material from households.

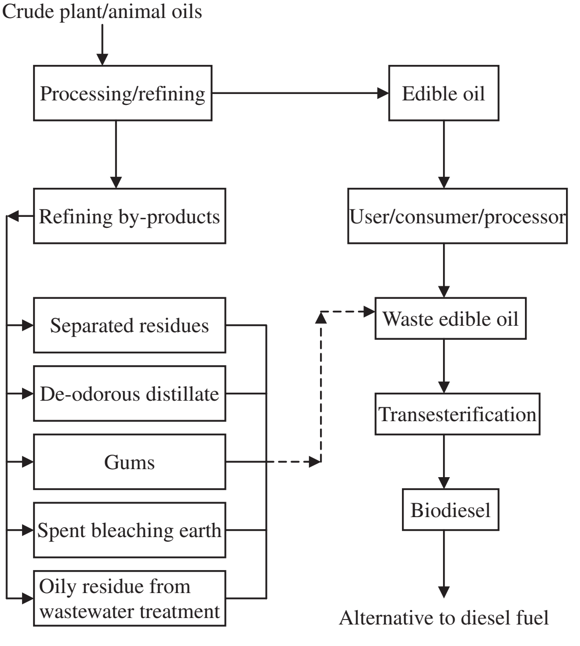


Fig. 1. Generation sources of waste edible oil [47].

5. Environmental regulations and policies for encouraging biodiesel fuel

5.1. Air pollution control act

In Taiwan, the basic law governing and promoting air pollution control and prevention is the Air Pollution Control Act (APCA), which was initially passed in May 1975, recently amended in June 2002. The goal of this act is set to prevent and control air pollution, safeguard public health, protect against air quality deterioration, and raise the living environment. Under the authorization of the APCA, there are two important regulations concerning emission and composition/property standards for transportation vehicles with biodiesel fuel, which are briefly described as follows:

5.1.1. Emission standards for vehicular air pollutants

According to the Article 34 of APCA, air pollutants emitted by transportation vehicles should comply with emissions standards, which shall be established by the central competent authority (i.e. EPA). The standard, named 'Emission Standards for Vehicular Air Pollutants', was first promulgated in June 1980, and recently amended in December 2003. In the Provision 5 of the regulation, driving cycle testing, judgment by visual determination, and instrument testing shall be performed to determine whether exhaust pipe emissions of diesel and alternative clean fuel engine motor vehicles comply with carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO_x), formaldehyde (HCHO), particulate pollutant, and black smoke standards, which is listed in Table 7. In view of the standards in Table 7, the emission standards of transportation vehicles to be implemented from January 1, 2007 will further reduce and/or set non-methane organic gases (NMOG), HCHO, NO_x and particulate levels for light-duty cargo trucks and passenger cars. For example, the NO_x and particulate levels for light-duty cargo trucks will be reduced from the former levels of 0.625 and 0.05 g/km, respectively, to 0.011 and 0.006 g/km, respectively. Clearly, such levels are far stricter than those of the former standards from January 1, 2004. The provision aims at pursuing clean fuels as a way to improve ambient air quality.

5.1.2. Standards governing composition and property of gasoline and diesel oils for vehicles

According to the Article 36 of APCA, the manufacture, import, sale or use of fuel supplied for use in transportation vehicles shall comply with the composition standards and property standards for fuel types determined by the central competent authority (i.e. EPA). The standards, named 'Standards Governing Composition and Performance of Gasoline and Diesel Oils for Vehicles', was first promulgated in August 2003, and thereafter amended in December 2004. In the Provision 4 of the regulation, the composition standards for vehicles with diesel oil shall comply with 50 ppmw (max.) in sulfur content, 48 (min.) in cetane index, and 35 vol.% (max.) in aromatics content from January 1, 2005. It is noted that the sulfur content in diesel fuel has been reduced from 350 to 50 ppmw, which will be expected to reduce the extents of corrosiveness and abrasion largely in diesel engines thus extending the life of the catalytic converter and improving environmental air quality. However, the composition standards will restrict biodiesel use because the cetane index in biodiesel is always <48. It implies that the usage of bio-diesel must be mixed with traditional diesel fuel, not absolutely used in diesel engines.

Table 7
Exhaust standards for inspection of new vehicle-models and testing of new-vehicles in Taiwan[a]

Date promulgated (Vehicle marketed)	Vehicle type	Exhaust standards[b]							
		CO	THC	NMHC	NMOG	NMHCC+NO_x	HCHO	NO_x	Particulate
July 1,1993	Heavy-duty vehicle[c]	10.0	1.3	–	–	–	–	6.0	0.70
	Light-duty vehicle[c]	6.2	0.5	–	–	–	–	1.4	0.38
July 1, 1999	Heavy-duty vehicle[a]	10.0	1.3	–	–	–	–	5.0	0.10
	Light-duty vehicle[b]	2.11	–	0.155	–	–	–	0.625	0.05
January 1, 2004	Heavy-duty vehicle[a]	10.0	1.3	–	–	–	–	5.0	0.10
	Light-duty cargo truck[d]	2.11	–	0.155	–	–	–	0.625	0.05
	Passenger car[e]	2.11	–	0.155	–	–	–	0.25	0.05
January 1, 2007	Heavy-duty vehicle[c]	10.0	–	–	–	2.4 (2.5)[f]	–	–	0.10
	Light-duty cargo truck[d]	2.61	–	–	0.056	–	0.011	0.044	0.006
	Passenger car[e]	2.61	–	–	0.056	–	0.011	0.044	0.006

[a]The exhaust was monitored under the specific driving cycle testing, which means use of a vehicle body dynamometer to simulate specific forms of driving and measurement of air pollutants emitted from a vehicle's exhaust pipe.

[b]Unit of exhaust standards for heavy-duty vehicle, g/bhp-hr; unit of exhaust standards for light-duty vehicle (cargo truck, passenger car, cargo-passenger truck), g/km. Abbreviations of air pollutants are denoted as follows: CO, carbon monoxide; THC, total hydrocarbons; NMHC, non-methane hydrocarbons; NMOG, non-methane organic gases; NO_x, nitrogen oxides; HCHO, formaldehyde.

[c]Heavy-duty vehicle: gross vehicle weight >3500 kg, or total seat (of passenger vehicle) <10; light-duty vehicle: gross vehicle weight <2500 kg. Exhaust standard of vehicle between gross weight of 2500 and 3500 kg may choose either heavy-duty vehicle or light-duty vehicle.

[d]Gross vehicle weight of cargo truck (including cargo-passenger truck) is <2500 kg.

[e]Gross vehicle weight is <3500 kg.

[f]Exhaust standard in parenthesis denotes that NMHCC+NO_x is <2.5 g/bhp-h, but NMHC must be <0.5 g/bhp-h.

Under the economic assistance by the central competent authority (i.e. EPA), some trash or municipal solid waste (MSW) cars in the metropolitan cities (e.g. Kaohsiung city and Tainan city) of Taiwan have used mixed diesel fuel with 20% biodiesel and 80% petroleum diesel in diesel engines. The results of exhaust analyses showed that the use of mixed diesel can reduce the extents of emissions by 25% in suspended particulate, 25.5% in carbon monoxide, 29% in hydrocarbons, 20% in black smoke, 100% in sulfur oxides, and 8.8% in nitrogen oxides [53]. Although some problems were inevitably related to the decrease of power and torque in the use of blends of biodiesel and diesel oil, there is a significant reduction in the dizzy odor from the traditional diesel oil.

5.2. *Waste disposal act*

With respect to the recycling of waste edible oils from commercial and industrial sectors in Taiwan, the basic law governing and promoting the waste recycling is the Waste Disposal Act (WDA). Notably, the new law referred to as 'Resource Recycling Act' (RRA) was passed and promulgated in July 2002. The important provisions or regulations concerning promotion on waste edible oil recycling can be consulted from the internet web (http://www.epa.gov.tw/eng/), and are briefly described as follows [51,52]:

5.2.1. General waste recovery, storage, collection and treatment methods and implementation standards

This regulation was first promulgated in accordance with the WDA in May 1987, and largely revised in May 1999, November 2002 and December 2004, respectively. According to the Provision 34 by the regulation, kitchen wastes (including waste edible oils or used frying/cooking oils) from households and non-enterprise street vendors shall be segregated from general wastes, and can be reused as organic fertilizer, culture earth, soil modifier, animal feed, or other approved purposes (e.g. as fuels or feedstock for producing biodiesel). Under the 'zero waste' policy, the EPA recently announced that the first stage of the Mandatory Garbage Sorting Plan will be effective on January 1, 2005. It means that about 50% of the citizens located in the cities of Taipei, Keelung, Hsinchu, Taichung, Chiayi and Tainan, and counties of Taichung and Yilan in Taiwan are required to sort their garbage into the three categories of resources, kitchen (food) waste and trash. Sorted food waste is currently converted to compost or feeding pigs. However, local governments are now planning on using biogas released from the anaerobic fermentation of solid-state food waste to generate electricity power, and producing biodiesel from waste edible oils in food wastes.

5.2.2. Regulations governing the permitting of industrial waste reuse

Under the authorization of the Article 39 of WDA, the Ministry of Economic Affairs (MOEA) has promulgated the regulations (i.e. 'Regulations Governing the Permitting of Industrial Waste Reuse by MOEA') since 2002. According to the definition by WDA, the reuse refers to the industrial waste reused by the waste producers themselves, or sold, or transferred or entrusted to others for reuse as fuel, raw material, and so on, or for other approved purposes. Regarding the recycling of waste edible oils from edible oil plant as described above, the reuse types for spent bleaching earth are designated as fresh material for cement, additives for oilseed dregs produced in the edible plant oil industry, raw material for organic fertilizer because it usually contains 20∼40 wt% edible oil by weight [48–50]. On the other hand, the reuse types for spent edible oil are designated as raw material for animal feed, soap and stearic acid. With the view of recycling these wastes rich in edible oils, it is expected that most of these industrial wastes will be gradually reused as energy sources (e.g. biodiesel fuel) under the regulatory amendment, policy encouragement and economic incentives.

6. Economic regulations and policies for financing biodiesel production

The implementation of a cleaner production plan for biodiesel production often requires substantial investment by enterprises. In order to encourage industries to actively participate in the product design, pollution prevention/resource recycling, energy saving and new/clean energy, the central government offers some tax benefits and financial incentives under the authorization of Statute for Upgrading Industries (SUI), which include tax deduction for investment, accelerated depreciation, tariff exemption and low interest loans.

In Taiwan, the promotion regulations related to biodiesel are mainly based on the Statute for Upgrading Industries (SUI), which was originally promulgated and became effective in December 1990 and was thereafter revised in January 1995, 2002 and February 2003, respectively. According to the newly revised SUI, important features concerning the

aspects of utilizing biomass energy utilities (including biodiesel production equipment) are briefly described as follows [39,54]:

1. To provide the financial incentives for any of the listed purposes (e.g. employing new and clean energy), service life of instruments and equipment purchased by a company may be accelerated to two years (Article 5).
2. To meet the requirement for industrial upgrading, an enterprise may credit 5~20% of the amount of fund disbursed for any of the listed purposes (e.g. The fund invested in the equipment or technology used for harnessing new and clean energy) against the amount of profit-seeking enterprise income tax payable for the then current year (Article 6).
3. The Executive Yuan (Cabinet) shall establish a development fund for low interest loans and make use of such development fund for the listed purposes (e.g. reduction of greenhouse gas effects) (Article 21).

Under the authorization of Article 6 of SUI, the regulation, known as 'Regulation of Tax Deduction for Investment in the Procurement of Equipments and/or Technologies by Energy conservation, or emerging/Clean Energy Organizations', has first been promulgated by the Ministry of Finance (MOF) in July 1997, and thereafter revised in November 1999, July 2000, September 2001, January 2003 and December 2004, respectively. These specified organizations shall be granted credits on the profit-seeking enterprise income tax for the current year if they use these equipments and/or technologies by themselves according to the following percentages of total purchase cost (>NT$600,000) in the current year:

- 11% for energy conservation or emerging/clean energy utilization equipments.
- 10% for energy conservation or emerging/clean energy utilization technologies.

If the profit-seeking enterprise income tax for the current year is not enough to be granted a tax deduction for investment, they may deduct the tax in the next 5-years for their profit-seeking enterprise income taxes.

7. Energy regulations and policies for promoting biodiesel fuel

7.1. Petroleum administration act

In response to the impacts of energy crisis and changes in the 1970s, 'The Energy Policy of the Taiwan Area' was first promulgated in April 1973 under the approval of Executive Yuan. Thereafter, the energy policy was further revised several times. In May 1998, a National Energy Conference was held in Taipei city for the purposes of formulating strategies and measures in response to dramatic changes in the domestic and international energy situations, economic situations and environmental issues. In summary, the important features of energy policy in Taiwan will aim at stabilizing energy supply, deregulating energy enterprise and enhancing environmental protection [39]. Under the described background, Petroleum Administration Act (PAA) was recently passed in October 2001. The main goals of this act are set to promote the sound development of the oil industry, and to safeguard the production and sales of oil in the commercial market.

According to the provision in the Article 38 of PAA, an enterprise engaging in the production of renewable energies of alcoholic gasoline, bio-diesel, and oil from recycled waste must apply for prior approval by the central competent authority (i.e. MOEA) for setting up the enterprise.

Under the authorization of PAA, the Ministry of Economic Affairs (MOEA) has promulgated the regulations (i.e. 'Measures for the Administration of enterprise Engaging in the Production of Renewable Energies of Alcoholic Gasoline, Biodiesel, and Oil from Recycled Waste') since December 2001. Recently, this regulation was further amended in July 2004. According to the Provision 2 in the regulation, the biodiesel is defined to refer to esters through the process of conversion (e.g. transesterification) by animal/plant oil or waste edible oil that is directly used or mixed with diesel as fuels. Also, the quality and composition of oil products produced from renewable energy enterprise must comply with the national standards prior to the marketing. Table 8 shows the national standards for the quality and composition of diesel fuels in Taiwan.

7.2. *Statute for renewable energy development (draft)*

In order to further promote and encourage the continual use of renewable energy, the Executive Yuan adopted the 'Renewable Energy Development Plan' in January 2002 prior to the pass of Statute for Renewable Energy Development by the congress (Legislative Yuan). In the Plan, important measures and promotions have been described in the previous study [39]. With respect to Statute for Renewable Energy Development (Draft)

Table 8
Specifications for diesel fuel in Taiwan

Item	Premium diesel[a]	Regular diesel[b]	Comment
Density (g/ml)	~0.825	~0.840	
Flash point (°C)	52 (Min.)	60 (Min.)	
Water and sediment (vol.%)	0.05 (Max.)	0.1 (Max.)	
Distillation temperature (°C)	338 (Max.)	357 (Max.)	90 vol.% recovered temperature
Kinematic viscosity (cSt)	1.9 (Min.), 4.1 (Max.)	1.9 (Min.), 4.3 (Max.)	40 °C
Ash (wt%)	0.01 (Max.)	0.02 (Max.)	
Sulfur (wt%)	0.035 (Max.)	1.0 (Max.)	
Copper strip corrosion	No.1 (Max.)	No.1 (Max.)	3 h at 50 °C
Cetane index	48 (Min.)	40 (Min.)	
Pour point (°C)	−3 (Max.)	10 (Max.)	
Ramsbottom carbon residue on 10% distillation residue (wt%)	0.1 (Max.)	0.15 (Max.)	

The specification was available from Chinese Petroleum Corporation (http://eng.cpc.com.tw). According to 'Standards for Governing Composition and Performance of Gasoline and Diesel Oil for Vehicle Use' revised and passed by Taiwan Environmental Protection Administration on December 15, 2004, the contents sulfur and aromatics, however, should be reduced to 50 ppmw (max.) and 35 vol.% (max.), respectively.

[a]For use on vehicle with medium-high rate diesel engine.

[b]For use on utilities (e.g. industrial/agricultural uses, train) with low-medium rate diesel engine. According to the regulation by Taiwan Environmental Protection Administration, the fuel was designated to be only used for military vehicle and internal engine in ship/boat since July 1, 1999.

passed by the Executive Yuan in August 2002 and now pending in the Legislative Yuan, it is summarized as follows:

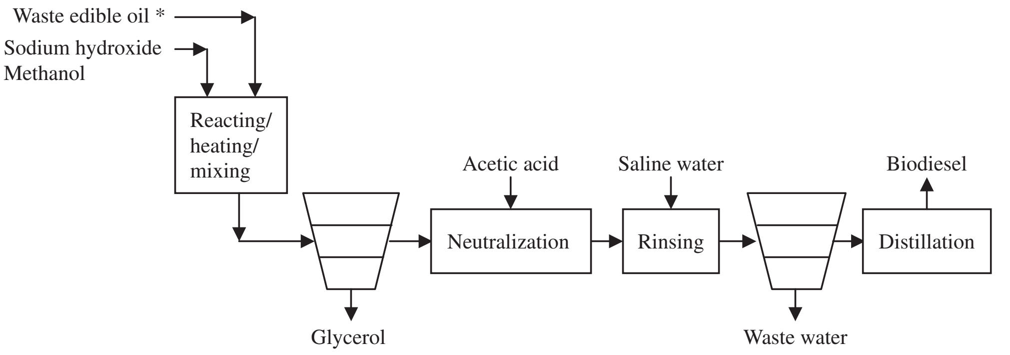
The central competent authority (i.e. Energy Bureau under the Ministry of Economic Affairs) is requested to set up the promotion goal in electricity generation from renewable energy. The total installation capacity aims at 6500 MW in the near future.

Electricity sector is requested to submit annually the amount of money for the purpose of establishing a special fund (called as Renewable Energy Development Fund) based on its current total electricity generation (exclusive of renewable energy source). The fund will be mainly used for subsidies of renewable energy development.

The procurement charge of electricity from renewable energy will be guaranteed at fixed rate of NT$ 2.0/kW-h (= US$ 0.06/kW-h). The fund described above will be used to subsidize the procurement fees.

8. Case study: biodiesel production from waste edible oils

In order to facilitate resource recycling, reduce the loading in the municipal sewer treatment plant and promote diversification of primary energy, this has led to demonstrate that waste edible oil was used as feedstock for the first biodiesel production plant in Southern Taiwan (Chiayi County) from October 2004, which was designed at the annual capacity of 3000 metric tons. From the process diagram (see Fig. 2) of the waste edible oil-to-biodiesel plant [36], the biodiesel production system includes a series of units including feedstock evaluation, transesterification, decanting separation (about 10 min), neutralization, water washing, decanting separation (about 30 min) and distillation. Stainless steel was used for the transesterification unit in the alkali-catalyzed process without the possibility of corrosion in operation. Prior to the transesterification proceeding, the waste edible oil from local suppliers must be tested for its acid value, iodine value and water content. Acid value is indicative of the content of free fatty acids, which are easily saponified with caustic catalyst (i.e. sodium hydroxide) to form saponifiable matters. Iodine value is used to measure the extent of unsaturated fatty acid, which has a decreasing trend as the quality deterioration of edible oil increased.Water content in the feedstock will give cause to form bulk solids in the alkali-catalyzed process, resulting in a negative impact



*The feedstock must be tested for its acid value, iodine value and water content prior to the transesterification.

Fig. 2. Process diagram of biodiesel fuel production by transesterification process in Taiwan [36].

on the downstream processing. Basically, the waste edible oil-to-biodiesel production system consists of transesterification system, neutralization/water washing system and distillation (purification) system, which are briefly described as follows:

8.1. Transesterification system

Waste edible oil and an appropriate amount of methanol with sodium hydroxide catalyst were placed into a reaction tank equipped with heater and stirrer. Reaction mixture was blended for 30 minutes at a temperature of 60 °C. Assuming that nearly 100% of the waste oil was converted to fatty acid methyl ester (FAME), the top (ester) layer was then separated from the down (glycerol) layer in a decanting funnel (gravity settler). Crude ester layer consists of FAME, minor components of unreacted oil and methanol, and small amounts of glycerol, catalyst residue and saponified matters. The by-product glycerol can be further purified and thus obtained as a valuable product.

8.2. Neutralization/water washing system

Due to the incomplete separation achieved by the first decanting process, the purpose of the neutralization step was to neutralize the residual alkali catalyst in the crude FAME by using a weak acid (i.e. acetic acid) solution. Then, the stream was further washed with saturated saline water and clean water, and thereafter poured into another decanting funnel, where the FAME in the crude oil was further separated from the glycerol, methanol and residual salts for 30 min at room temperature.

8.3. Distillation (purification) system

In order to produce a high quality of biodesel fuel similar to the specifications of diesel fuel, the distillation was applied to purify FAME in the upper ester layer of second decanting funnel. A partial condenser was used to provide simple separation of the FAME (as a liquid distillate) from trace amounts of water and methanol (as vent gases) in the column overhead. On the other hand, the unreacted oil remained at the bottom of distillation column. The bottom residue can be transferred to the transesterification unit, or reused as liquid fuel. Data on the properties of resulting biodiesel fuel product, which was provided by the demonstration plant, is shown in Table 9.

Compared to the specifications in Table 8, the properties of biodiesel fuel make complete similarity to those of petroleum-based diesel fuel. At an early stage, the waste edible oil-based biodiesel fuel will be blended with petroleum-based diesel fuel as power source in city bus, trash collection truck and farming machine. As described above, it was reasonably estimated that the potential generation of biodiesel fuel amounted up to 63,000 metric tons per year in Taiwan based on approximately 70,000 metric tons per year of waste edible oil generation. According to the data, energy and environmental benefits from waste edible-to-biodiesel were quantitatively analyzed as follows:

- Energy output: 7.3×10^4 KLOE (based on the heating values of general diesel: 0.84 metric tons/kiloliter, and 0.9778 KLOE/kiloliter [1]
- Waste reduction: 7.0×10^4 metric tons/year (based on the generation factor in Japan: 10% of edible oil consumption) [9,45]

Table 9
Properties of biodiesel fuel produced from the demonstration plant in Taiwan

Item	Biodiesel sample 1	Biodiesel sample 2	Analysis method
Density (g/ml)	0.8823	0.8826	ASTM D4052
Flash point (°C)	180	173	ASTM D93
Water and sediment (vol.%)	0.000	0.000	ASTM D2709
Distillation temperature (°C)	342.6	342.2	ASTM D86
Kinematic viscosity (cSt)	4.7116	4.7568	ASTM D445
Ash (wt.%)	0.0059	0.0083	ASTM D482
Sulfur (wt.%)	0.0005	0.00056	ASTM D5453
Copper strip corrosion	1	1	ASTM D130
Cetane index	45.9	45.8	ASTM D976
Pour point (°C)	6	6	ASTM D97
Ramsbottom carbon residue on 10% distillation residue (wt%)	0.02	0.01	ASTM D4530
Neutralization number (mg KOH/g)	0.79	0.53	ASTM D664
Turbidity point (°C)	10	11	ASTM D2500
Phosphrous (wt.%)	0.0003	0.0004	ASTM 5185(M)
Heating value (kcal/kg)	9486	9470	Adiabatic calorimeter

The properties were available from the demonstration plant.

- Equivalent carbon dioxide (CO_2) mitigation: 2.0×10^5 metric tons/year (based on the emission factors of diesel fuel by IPCC method: 43.33 TJ/10^3 metric ton, 20.2 metric ton C/TJ, fraction (= 0.99) of carbon oxidized) [55].

9. Conclusion and prospects

In the past decade, energy consumption related to environmental pollution and supply diversification has been the focus of environmental protection and economic development for pursuing sustainable development and creating renewable energy in Taiwan. Because of the limited petroleum reserves and increased environmental concerns, alternate fuels from agricultural resources have become increasingly important in the near future. From the viewpoints of resource recycling and energy utilization, biodiesel fuel from waste edible oil for diesel engines can be considered as one of green energies. Under the policy encouragement and financial subsidies, the triglyceride-based diesel fuel has been relatively attractive in Taiwan. It is undoubtedly expected that the Statute for Renewable Energy Development under enactment will further drive the gradual displacement of traditional fossil energy. However, the fact that biodiesel is still expensive that fossil fuel has been a major barrier that prevents its widespread use. To greatly promote the use of biodiesel fuel as an alternative to petroleum-based fuels in Taiwan, the following measures are recommended and enhanced:

- Increase the subsidy to use biodiesel fuel in diesel engines under the support of special funds such as Air Pollution Control Fee and Petroleum Fund.
- Establish the national specification standards for biodiesel fuel like the American Society of Testing and Materials (ASTM) standard (D 6751) and German standard (DIN V 51606).

- Grant food enterprises to build another waste edible oil-to-biodiesel demonstration plant in Northern Taiwan for the purpose of reducing transportation and production costs.
- Demonstrate commercial feasibility on utilizing spent bleaching earth as one of waste edible oil sources, which was mostly disposed of to landfills or composted in soils without any efficient utilization.
- Promote the cultivation of oilseed crops such as sunflower and corn in response to the rice production in decline since Taiwan's entry into the World Trade Organization (WTO) in 2002.
- Regulate the return of waste edible oil to be regenerated due to the dietary health, and illegal dumping into sewer system and trash because it has been listed as one of recyclable items.

References

[1] Ministry of Economic Affairs (MOEA). Taiwan energy statistics annual report. Taipei, Taiwan: MOEA; 2004.
[2] Ministry of Economic Affairs (MOEA). The energy situation in Taiwan (ROC). Taipei, Taiwan: MOEA; 2002.
[3] Bishop PL. Pollution prevention: fundamentals and practice. Boston, MA: McGraw-Hill; 2002.
[4] Srivastava A, Prasad R. Triglycerides-based diesel fuels. Renew Sustain Energy Rev 2000;4:111–33.
[5] Fabri J, Dabelstein W, Reglitzky A, Schutze A, Reders K. Automotive fuels. In: Bohnet M et al., editor. Ullmann's encyclopedia of industrial chemistry, 6th ed, vol. 4. Weinheim, Germany: Wiley-VCH; 2003.
[6] Barnwal BK, Sharma MP. Prospects of biodiesel production from vegetable oils in India. Renew Sustain Energy Rev 2005;9:363–78.
[7] Hasenhuettl GL. Fats and fatty oils. In: Kroschwitz JI, Howe-Grant M, editors. Kirk-Othmer encyclopedia of chemical technology. 4th ed. New York, NY: Wiley; 1994.
[8] Otera J. Transesterification. Chem Rev 1993;93:1449–70.
[9] Murayama T. Evaluating vegetable oils as a diesel fuel. INFORM 1994;5:1138–45.
[10] Krawczyk T. Biodiesel alternative fuel makes inroads but hurdles remain. INFORM 1996;7:801–15.
[11] Klass DL. Biomass for renewable energy, fuels, and chemicals. San Diego, CA: Academic Press; 1998.
[12] Ma F, Hanna MA. Biodiesel production: a review. Bioresour Technol 1999;70:1–15.
[13] Fukuda H, Kondo A, Noda H. Biodiesel fuel production by transesterification of oils. J Biosci Bioeng 2001;92:405–16.
[14] Demirbas A. Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: a survey. Energy Convers Manag 2003;44:2093–109.
[15] Graboski MS, McCormick RL. Combustion of fat and vegetable oil derived fuels in diesel engines. Prog Energy Combust Sci 1998;24:125–64.
[16] Carraretto C, Macor A, Mirandola A, Stoppato A, Tonon S. Biodiesel as alternative fuel: experimental analysis and energetic evaluations. Energy 2004;29:2195–211.
[17] Lin HA, Lin CY. Analysis of fuel contents and properties of biodiesel (in Chinese). Combust Quart 2004; 13(4):4–10.
[18] Ramadhas AS, Jayaraj S, Muraleedharan C. Use of vegetable oils as I.C. engine fuels—a review. Renew Energy 2004;29:727–42.
[19] Mittelbach M, Enzelsberger H. Transesterification of heated rapeseed oil for extending diesel fuel. J Am Oil Chem Soc 1999;76:545–50.
[20] Alcantara R, Amores J, Canoira L, Fidalgo E, Franco MJ, Navarro A. Catalytic production of biodiesel from soy-bean oil, used frying oil and tallow. Biomass Bioenergy 2000;18:515–27.
[21] Mittelbach M, Gangl S. Long storage stability of biodiesel made from rapeseed and used frying oil. J Am Oil Chem Soc 2001;78:573–7.
[22] Dorado MP, Ballesteros E, De Almeida JA, Schellert C, Lohrlein HP, Krause R. An alkali-catalyzed transesterification process for high free fatty acid waste oils. Trans ASAE 2002;45:525–9.

[23] Lee KT, Foglia TA, Chang KS. Production of alkyl ester as biodiesel from fractionated lard and restaurant grease. J Am Oil Chem Soc 2002;79:191–5.
[24] Al-Widyan MI, Al-Shyoukh AO. Experimental evaluation of the transesterification of waste palm oil into biodiesel. Bioresour Technol 2002;85:253–6.
[25] Supple B, Howard-Hildige R, Gonzalez-Gomez E, Leahy JJ. The effect of steam treating waste cooking oil on the yield of methyl ester. J Am Oil Chem Soc 2002;79:175–8.
[26] Tomasevic AV, Siler-Marinkovic SS. Methanolysis of used frying oil. Fuel Process Technol 2003;81:1–6.
[27] Zhang Y, Dube MA, McLean DD, Kates M. Biodiesel production from waste cooking oil: 1. Process design and technological assessment. Bioresour Technol 2003;89:1–16.
[28] Cetinkaya M, Karaosmanoglu F. Optimization of based-catalyzed transesterification reaction of used cooking oil. Energy Fuels 2004;18:1888–95.
[29] Murayama T, Fujiwara Y, Noto T. Evaluating waste vegetable oils as a diesel fuel. Proc Inst Mech Engrs, Part D. J Automobile Eng 2000;214:141–8.
[30] Dorado MP, Ballesteros E, Arnal JM, Gomez J, Lopez Gimenez FJ. Testing waste olive oil methyl ester as a fuel in a diesel engine. Energy Fuels 2003;17:1560–5.
[31] Tashtoush G, Al-Widyan MI, Al-Shyoukh AO. Combustion performance and emissions of ethyl ester of a waste vegetable oil in a water-cooled furnace. Appl Thermal Eng 2003;23:285–93.
[32] Yahya U, Yucel T, Merve C, Filiz K. The engine tests of biodiesel from used frying oil. Energy Sources 2004;26:927–32.
[33] Usta N, Ozturk E, Can O, Conkur ES, Nas S, Con AH, et al. Combustion of biodiesel fuel produced from hazelnut soapstock/waste sunflower oil mixture in a diesel engine. Energy Conversion Manag 2005;46: 741–55.
[34] Cetinkaya M, Ulusoy Y, Tekin Y, Karaosmanoglu F. Engine and winter road test performances of used cooking oil originated biodiesel. Energy Conversion Manag 2005;46:1279–91.
[35] Wu YP, Lin YF. The study of the combustion characteristic of biodiesel made from recycled cooking oil (in Chinese). Combust Quart 2004;13(4):11–8.
[36] Hsien HT. Green energy—biodiesel demonstration plant (in Chinese). Energy Monthly 2004;October:22–4.
[37] Directorate-General of budget accounting and statistics (Executive Yuan, Taiwan). Available from: http://www.eng.dgbas.gov.tw/.
[38] Tsai WT. Bioenergy from landfill gas (LFG) in Taiwan. Renew Sustain Energy Rev [in press] DOI:10.1016/j.rser.2005.01.001.
[39] Tsai WT, Chou YH. Overview of environmental impacts, prospects and policies for renewable energy in Taiwan. Renew Sustain Energy Rev 2005;9:119–47.
[40] Council of Agriculture (COA). Food supply & utilization. Taipei, Taiwan: COA; 2004.
[41] Council for Economic Planning and Development (CEPD). Taiwan statistical data book. Taipei, Taiwan: CEPD; 2004.
[42] Taiwan Vegetable Oil Manufacturers Association (Taipei, Taiwan). Available from: http://www.tgfdf.gov.tw/.
[43] Wang UI. Current status and prospects of vegetable oils in Taiwan (in Chinese). Ind Survey Technol 2001;138:1–21.
[44] Wu SJ, Chang YH, Fang CW, Pan WH. Food sources of weight, calories and three macro-nutrients: NAHSIT 1993–1996. Nutr Sci J 1999;24:41–58.
[45] Yoshitomi Kazuhito. Recovery, treatment and utilization of spent bleaching earth and used plastic bottles in oil processing industry in Japan (in Chinese, translated by Lee JF). Soybean & processing technical seminar: pollution control & quality management, January 16, 1997, Taipei, Taiwan.
[46] Chou GL, Lee HT, Shiau WS, Wu LH. Study on promoting new and clean energy in Taiwan area-demonstration analysis of biodiesel (in Chinese). Energy Quart 2002;32(1):105–15.
[47] Chen JW. Resource recycling and environmental protection of waste edible oils (in Chinese). Chinese Food Ind 1997;(30):62–7.
[48] Wener Z. Spent bleaching earth-practical solutions. INFORM 1994;5:1375–7.
[49] Nebergall R. Commercial spent bleaching earth regeneration. INFORM 1996;7:206–11.
[50] Al-Zahrani AA, Daous MA. Recycling of spent bleaching clay and oil recovery. Trans IChemE 2000;78:224–8.
[51] Tsai WT, Chou YH. A review of environmental and economic regulations for promoting industrial waste recycling in Taiwan. Waste Manag 2004;24:1061–9.

[52] Tsai WT, Chou YH. Government policies for encouraging industrial waste reuse and pollution prevention in Taiwan. J Cleaner Prod 2004;12:725–36.
[53] Chang FT. On the road to use biodiesel fuel in trash truck (in Chinese). Kaohsiung Green Coordinate 2004;No16.
[54] Ministry of Finance (Taiwan). Available from: http://www.mof.gov.tw.
[55] International Panel on Climate Change (IPCC). Guidelines for national greenhouse gases inventories. Paris, France: IPCC; 1997.